Antenna Properties and their impact on Wireless System Performance

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ABSTRACT: Since the first demonstration of wireless technology in 1886 by Heinrich Hertz and its first practical radio application by Guglielmo Marconi in 1901, the antenna has been a key building block in the construction of wireless communications systems. In many instances, the antenna is not considered critical in the initial system design, however, it is the single device that allows RF energy to transition between wire transmission lines and free space. Since the days of Hertz, antennas have advanced from a simple wire dipole to more complex structures such as helical antennas, parabolic reflectors, Yagis, microstrip patch arrays, etc. The purpose of this article is to provide an overview of fundamental antenna properties, antenna performance characteristics, system RF propagation characteristics and related tradeoff issues. This article will also provide a discussion of how the antenna and RF propagation properties affect overall wireless system performance. This information can be used to establish antenna selection criteria for optimum system performance.

INTRODUCTION

In the design and installation of wireless communication systems, it is necessary for system design engineers, operators and many times, installers, to have a fundamental knowledge of antenna performance and RF propagation characteristics. This knowledge will assist these individuals with the proper selection of system antennas and their subsequent mounting location and orientation in an effort to ensure optimum system coverage and performance.

A properly selected antenna system has the capability of improving overall system performance and may lead to a reduction in system cost if the overall number of stations or access points can be reduced. Conversely, a poorly selected antenna system may degrade system performance and may lead to an increase in system cost.

The following sections will provide a discussion of fundamental antenna and RF propagation properties and how these affect wireless system performance. These discussions are intended to provide system engineers and operators with a basic knowledge of antenna properties and antenna selection criteria.

In addition to antenna performance, other factors that influence antenna selection include cost, size, and appearance. In the selection of an antenna system, there will always be tradeoffs between these four issues. It is hoped that this article will allow system engineers to better understand these tradeoffs so that overall system performance can be optimized.

I FUNDAMENTAL ANTENNA PROPERTIES

The first concept to understand regarding antennas is that they are passive devices. To operate, they require no supply voltage. They do not alter nor process RF signals and they do not amplify RF energy. If they are 100% efficient, they radiate no more power than is delivered to their input terminal.

The basic properties that are used to describe the performance of an antenna include impedance and VSWR (Voltage Standing Wave Ratio), amplitude radiation patterns, 3 dB beamwidth, directivity, gain, polarization and finally, bandwidth. These properties and their impact on system performance are discussed in the following sections.

Impedance and VSWR

In order to achieve maximum energy transfer between a wire or coaxial transmission line and an antenna, the input impedance of the antenna must identically match the characteristic impedance of the transmission line. If the two impedances do not match, a reflected wave will be

generated at the antenna terminal and travel back towards the energy source. This reflection of energy results in a reduction in the overall system efficiency. This loss in efficiency will occur if the antenna is used to transmit or receive energy.

The resultant voltage wave on the transmission line is the combination of both the incident (source) and reflected waves. The ratio between the maximum voltage and the minimum voltage along the transmission line is defined as the Voltage Standing Wave Ratio or VSWR.

The VSWR, which can be derived from the level of reflected and incident waves, is also an indication of how closely or efficiently an antenna's terminal input impedance is matched to the characteristic impedance of the transmission line. An increase in VSWR indicates an increase in the mismatch between the antenna and the transmission line.

Typically, most wireless communications systems operate with a 50 Ohm impedance and therefore, the antenna must be designed with an impedance as close to 50 Ohms as possible. The antenna VSWR is then an indication of how close the antenna impedance is to 50 Ohms. A 1.0:1 VSWR would indicate an antenna impedance of exactly 50 Ohms. In many systems, the antenna is required to operate with a VSWR better than 1.5:1

To indicate how increased VSWR impacts overall system performance, Table 1 below details the percentage of power reflected by the antenna, and the resultant overall transmission loss, for several typical VSWR values. For a 1.5:1 VSWR, the transmission loss is approximately 0.2 dB or a 4.0% reduction in efficiency. It is also important to note that some transmitter circuits decrease their output power with increasing antenna VSWR. This factor varies with each transmitter and is not quantified in this discussion.

Note: The term dB is a logarithmic expression of the ratio between two signal levels. For voltage the dB relationship is: $dB = 20*\log_{10}(V2/V1)$. For power the dB relationship is $dB = 10*\log_{10}(P2/P1)$.

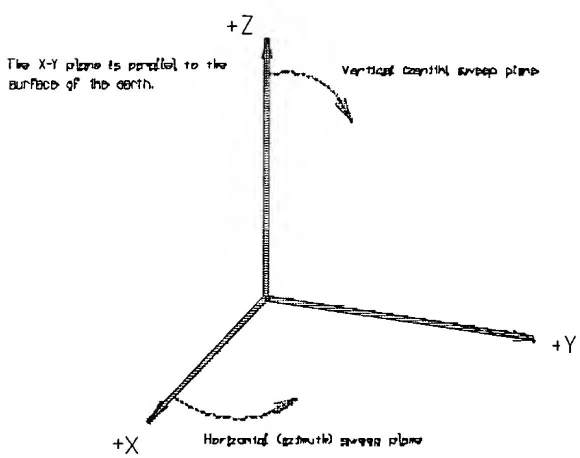
Table 1. Percent Reflected Power and Transmission Loss as a Function of VSWR.

VSWR	Percent Reflected Power	Transmission Loss (dB)
1.0:1	0.0	0.0
1.25:1	1.14	0.05
1.5:1	4.06	0.18
1.75:1	7.53	0.34
2.0:1	11.07	0.51
2.25:1	14.89	0.70
2.5:1	18.24	0.88

Radiation Patterns and 3 dB beamwidth

The radiation patterns of an antenna provide the information that describes how the antenna directs the energy it radiates. As stated earlier, an antenna cannot radiate more total energy than is delivered to its input terminals. All antennas, if 100% efficient will radiate the same total energy, for equal input power, regardless of pattern shape.

Antenna radiation patterns are typically presented in the form of a polar plot for a 360 degree angular pattern in one of two sweep planes. The most common angular sweep planes used to describe antenna patterns are a horizontal or azimuth sweep plane and a vertical or elevation (zenith) sweep plane. A graphical representation of these planes and a typical polar pattern are presented in Figure 1. Radiation patterns are generally presented on a relative power dB scale.



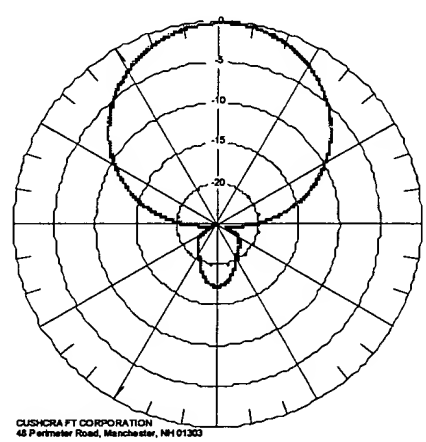


Figure 1. Graphical Representation of the Horizontal and Vertical Sweep Planes and a Typical Polar Pattern Plot.

In many cases, the convention of an E-plane and H-plane sweep or pattern is used in the presentation of antenna pattern data. The E-plane is the plane that contains the antenna's radiated electric field potential while the H-plane is the plane that contains the antenna's radiated magnetic field potential. These planes are always orthogonal. For dipole and Yagi antennas, the E-plane is always in the plane parallel to the linear antenna elements.

Once the antenna pattern information is detailed in a polar plot, some quantitative aspects of the antenna pattern properties can be described. These quantitative aspects generally include the 3 dB beamwidth (1/2 power level), directivity, side lobe level and front to back ratio. To further understand these concepts, we first consider the fundamental reference antenna, the point source. A point source is an imaginary antenna that radiates energy equally in all directions such that the antenna pattern is a perfect sphere as shown in Figure 2. This antenna is said to be an omnidirectional isotropic radiator and has 0 dB directivity. In practice, when an antenna is said to be omnidirectional, it is inferred that this is referenced only to the horizontal or azimuth sweep plane.

For any practical antenna, there will always be some specific direction of maximum radiated energy as shown in Figure 3. The relative level of the maximum radiated energy to that of an isotropic radiator is termed directivity. This is a relative measure of how an antenna focuses or directs the energy it radiates. The higher the directivity, the more focused the antenna pattern. It is important to note that no antenna can have a directivity less than 0 dB.

The 3 dB beamwidth of antenna is simply a measure of the angular width of the –3 dB points on the antenna pattern relative to the pattern maximum. These –3 dB points on the pattern represent the point on the pattern where the power level is _ of the value at the pattern maximum. Generally, the 3 dB beamwidth is expressed separately for each of the individual pattern sweep planes.

The antenna side lobe level and front to back ratio are measures of how much energy the antenna radiates outside of its main beam. The side lobe level describes the relative level of minor pattern lobes outside the main beam while the front to back ratio describes the level of radiation directly opposite the main beam. Ideally, these levels should be as low as possible since they reduce the directivity and hence efficiency of the main beam. Energy radiated outside of the main beam of the antenna reduces the overall antenna efficiency. For transmit antennas, the presence of side and back lobes may also cause interference to other nearby receive sites. For receive antennas, the presence of side and back lobes may generate interference into the receive system from surrounding transmit sites.

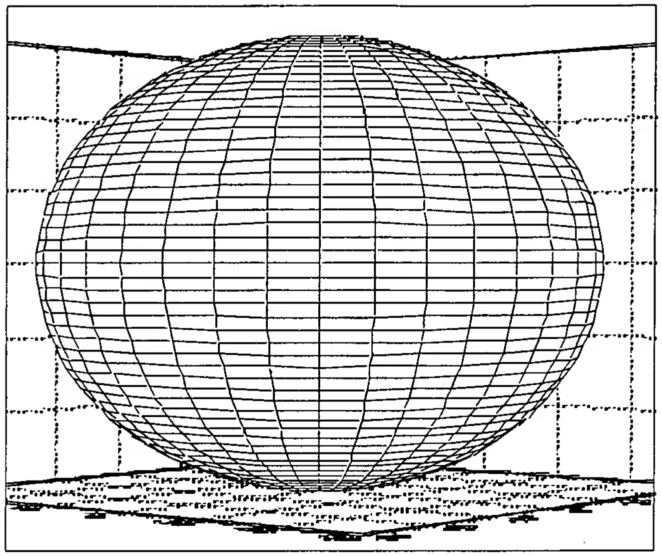


Figure 2. Spherical Radiation Pattern of a Point Source Antenna.

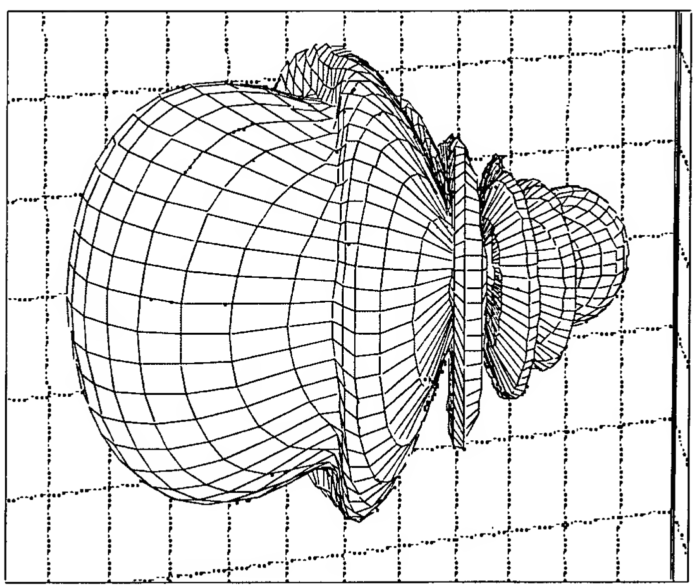


Figure 3. A Typical Radiation Pattern of a Practical Antenna.

Gain

The gain of an antenna is essentially a measure of the antenna's overall efficiency. If an antenna were 100% efficient, it would have a gain equal to its directivity. There are many factors that affect and reduce the overall efficiency of an antenna. Some of the most significant factors that impact antenna gain include the following:

Impedance/VSWR: As mentioned in previous sections, the VSWR provides an indication of how closely the impedance of an antenna matches the impedance of the connecting transmission line. If an impedance mismatch exists, a reflected wave will be generated towards the energy source. This reflected wave reduces the level of energy transferred between the transmission line and the antenna. This effectively reduces the total level of radiated energy relative to the energy incident at the antenna's input terminal. This loss of energy reduces the effective gain of the antenna.

Matching Network Losses: In general, the terminal impedance of an antenna will not exactly match the characteristic impedance of the connecting transmission line to the required VSWR level. In order to align or match these impedances, a matching circuit or network is constructed at the antenna terminals. This matching network may typically consist of lumped circuit elements (inductors and/or capacitors), transformers (coaxial or microstrip) and microstrip circuitry. In any such matching circuit, energy is delivered to both the matching components and the antenna. Additionally, some of the matching components may be inherently lossy and will dissipate energy delivered to the antenna. The losses in these matching components may be minimal but do reduce the effective gain of the antenna.

Material (metal/dielectric) Losses: All antennas are constructed of discrete materials which include both metallic and non metallic components. If these components are used as part of the actual radiating structure, such as wire elements or dielectric substrates, they will dissipate some energy as heat rather than radiating it. The energy lost as heat in these components reduces the effective gain of the antenna.

Radome Losses: In many cases, the radiating structure of the antenna is housed inside a radome for protection from the operating environment. In this case, the energy radiated by the antenna must pass through the radome. In most cases, some amount of radiated energy is dissipated as it passes through the antenna radome. This dissipated energy reduces the effective gain of the antenna.

Considering all of these factors, it would appear that the antenna must overcome a lot of adversity in order to achieve acceptable gain performance. These loss factors are well known to antenna design engineers and can be eliminated or minimized with proper antenna design. Typically, efficiency levels of 85% to 95% are not uncommon and are reflected in the calibrated gain curves provided with antenna performance data.

Polarization

The polarization of an antenna describes the orientation and sense of the radiated wave's electric field vector. All radiated waves are generally defined as elliptically polarized. In this general case, the antenna's total electric field (E-field) has two components that lie in the same plane. These two E-field components may be of different strength and are oriented at different angles (phase relationship). The two most known and common cases of elliptical polarization are circular; in which the two E-field components are equal in magnitude and oriented at 90 degrees to each other (90 degrees out of phase), and linear; in which the wave has a single E-field component. These concepts are graphically depicted in Figure 4. The term axial ratio is used to define the relative strength of the two E-field components in an elliptically polarized wave. For pure circular polarization the axial ratio is 0 dB and for linear polarization the axial ratio is ∞.

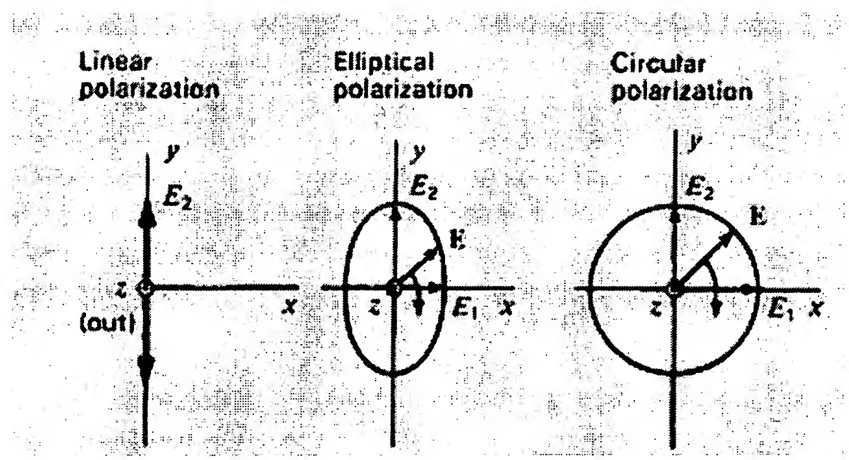


Figure 4. Graphical Depiction of Polarization Orientation.

The important performance issue relative to signal polarization is that maximum energy transfer between a transmitting and receiving antenna will only occur if both antennas have identical axial ratio, identical polarization sense and the same spatial orientation. It is assumed that nothing in the propagation path causes the signal polarization to change (polarization distortion).

With linearly polarized transmit and receive antennas, the polarization of each must be of the same orientation to achieve maximum energy transfer between the two antennas. If the two linearly polarized antennas are not identically oriented, there will be a reduction in energy transfer due to polarization mismatch. Table 2 on the following page provides a summary of polarization

mismatch loss between two linearly polarized waves (antennas) that do not have the same angular orientation.

Table 2. Polarization Mismatch Between Two Linearly Polarized Waves as a Function of Angular Orientation.

Orientation Angle	Polarization Mismatch (dB)
0.0 (aligned)	0.0
15.0	0.3
30.0	1.25
45.0	3.01
60.0	6.02
75.0	11.74
90.0 (orthogonal)	∞

One common misconception in the communication industry is that there is always a 3 dB polarization mismatch between linearly and circularly polarized antennas. This will only be true if one antenna is purely circularly polarized and the other is purely linearly polarized. In most cases, it is unlikely that the circularly polarized antenna will have an axial ratio of 0 dB and field components exactly 90 degrees out of phase. Similarly, it is possible that the linearly polarized antenna may have another minor field component.

Table 3 provides a summary of the polarization mismatch between a linearly polarized and a circularly polarized wave as a function of the circularly polarized wave's axial ratio. It is assumed that the circularly polarized wave's field components are orthogonal.

Table 3. Polarization Mismatch between a Linearly and Circularly Polarized Wave as a Function of the Circularly Polarized Wave's Axial Ratio.

Axial Ratio	Minimum Polarization Loss (dB) •	Maximum Polarization Loss (dB) ••
0.00	3.01	3.01
0.25	2.89	3.14
0.50	2.77	3.27
0.75	2.65	3.40
1.00	2.54	3.54
1.50	2.33	3.83
2.00	2.12	4.12
3.00	1.77	4.77
4.00	1.46	5.46
5.00	1.19	6.19

10.00	0.41	10.41

• Minimum polarization loss occurs when the strongest linear field component of the circularly polarized wave is identically aligned with the linearly polarized wave.
•• Maximum polarization loss occurs when the weakest linear field component of the circularly polarized wave is aligned with the linearly polarized wave.

Bandwidth

The term bandwidth simply defines the frequency range over which an antenna meets a certain set of specification performance criteria. The important issue to consider regarding bandwidth is the performance tradeoffs between all of the performance properties described above. These tradeoffs will be described in more detail in the following sections.

Summary and Related Performance Tradeoff Issues

The antenna properties described above are all related to varying degree. In selecting or designing an antenna system, the tradeoffs between all of these performance properties must be considered in order to ensure optimum system performance. These factors must also be weighed against factors beyond the actual antenna properties such as those that will be discussed in the next section regarding RF propagation.

In all cases, the required or specified performance properties of an antenna can only be achieved over a limited frequency bandwidth. The extent of this realizable bandwidth is a function of the performance requirements, antenna type selected and the antenna size relative to the operating wavelength. Typically, optimum antenna performance is achieved at the center frequency of the operating band.

In the case of VSWR, system performance is typically degraded at the ends of the operating frequency band. The overall effect on system performance is a decrease in antenna gain due to impedance mismatch losses.

The antenna's radiation patterns, beamwidth, directivity (gain) and bandwidth are more directly related. As with VSWR, performance is usually degraded at the end of the operating band.

The 3 dB beamwidth and directivity (gain) are inversely proportional. As the antenna beamwidth decreases, the directivity increases. These parameters are also related to the antenna size or aperture. As the antenna aperture or size increases with respect to the operating wavelength, the radiation beamwidth decreases. Therefore, to achieve increased antenna gain, it is required that the antenna size increase.

For linearly polarized antennas, polarization is generally not a function of bandwidth, however, this is not always the case for circularly polarized antennas. In most cases, the

polarization axial ratio for a circularly polarized antenna increases at the edges of the operating frequency band.

II RF PROPAGATION

In addition to the antenna properties described above, other factors beyond the actual wireless system hardware affect overall system performance. These factors can be simply summarized as those that affect the propagation of RF signals. These factors and how they affect system performance are discussed in the following sections.

Path Loss

The easiest, and perhaps least ambiguous factor to discuss is path loss. Quite simply, as RF signals propagate, they are attenuated. The free space propagation loss factor is described by the following equation,

$$\text{Path Loss (dB)} = 20 \log_{10} (4\pi r/\lambda)$$

where r is the path distance and λ is the free space wavelength.

Based upon this formula, some typical path loss values are presented for various wireless frequencies in Table 4 below.

Table 4. Typical Free Space Path Loss Values (dB) for Various Wireless Frequencies

Distance/Frequency	915 MHz	1920 MHz	2.450 GHz	5.7875 GHz
100 meters	71.68	78.11	80.23	87.70
200 meters	77.69	84.13	86.25	93.72
500 meters	85.66	92.09	94.21	101.68
1,000 meters	91.68	98.11	100.23	107.70
2,000 meters	97.69	104.13	106.25	113.72
5,000 meters	105.66	112.09	114.21	121.68
10,000 meters	111.67	118.11	120.23	127.70

Reviewing the table above, it is obvious that path loss is a significant problem in achieving system performance. The only possible methods to minimize path loss effects are to increase transmit power, system gain, lower the operating frequency or increase receiver sensitivity. Unfortunately, these are not always viable options. It is also important to note that path loss increases by a factor of approximately 6 dB for every doubling of frequency or path distance. This is significant to realize since this means a doubling of antenna or system gain (+3 dB) will not double the propagation distance. To double the useable coverage or path distance, the antenna or system gain would have to increase by a factor of four (+6 dB).

In addition to the free space path loss, RF signals in a wireless system will be attenuated as they pass through objects such as foliage, walls and buildings. The level of signal attenuation in these instances is more difficult to determine since the nature of the foliage, walls and buildings is complex and may be unknown. Many efforts have been focused on both experimentally and numerically modeling these effects. Additional path loss attenuation of 10 to 20 dB or greater can be experienced as signals propagate through these objects.

Multipath Fading

The phenomena of multipath fading is perhaps one of the most serious of the propagation problems due its potentially detrimental impact on system performance and the fact that it is difficult to accurately predict in a wireless environment. Usually, system designers attempt to eliminate its impact through various system design techniques that will be briefly discussed at the end of this section.

Multipath fading in a wireless system is the result of multiple signals from the same RF source arriving at the receive site via many unique paths. Essentially, as an RF signal is radiated from an antenna, it strikes many objects such as walls, buildings, towers, the earth, etc. After striking these objects, the RF signal is time delayed, attenuated, reflected or diffracted and arrives at the receive site at a different amplitude, phase and perhaps time sequence than the directly received signal. At any given instant in time, the total signal received by the antenna is the vector sum of the direct signal and all of all the multipath signals. Depending upon the amplitude and phase of the individual signals, the total signal may be only slightly affected or it may be canceled entirely.

From an antenna perspective, multipath is difficult to eliminate if the receive antenna pattern is not directed at a specific transmit antenna. If the receive and transmit antenna patterns are not required to be omnidirectional, the antennas can possibly be made directive enough to minimize multipath interference. If the receive and transmit antenna patterns are required to be omnidirectional, multipath interference will be difficult to eliminate through antenna design. In this case, the system designers attempt to use other techniques to minimize or eliminate signal loss caused by multipath. These techniques include the use of spread spectrum systems, optimization of antenna locations, elimination of reflective objects, and diversity techniques.

With spread spectrum systems, the total RF signal is distributed over a wide frequency bandwidth. In this type of system, multipath will generally not affect the entire bandwidth thereby minimizing its impact on system performance. In diversity based receive systems, spatial, polarization, field or frequency diversity may be used at the receive site to minimize multipath interference. The most common techniques used are spatial and polarization diversity. With spatial diversity, two antennas are required and are separated horizontally such that the two antennas are not subject to the same multipath effects. With polarization diversity, two oppositely polarized antennas can be co-located and will provide diversity through the two different polarizations received. In this case, it is important to understand the nature of the received wave polarization.

In addition to antenna diversity techniques, some receive systems use different methods of combining the received antenna signals in order to enhance system performance. In these systems, one or both of the received signals are altered to enhance performance. For example, in a spatial diversity system, one of the signals received by an antenna may have its phase changed to match that of the other antenna signal. In doing so, the two signals can be combined to enhance system performance. The system manufacturers more appropriately address details of these techniques.

Interference and Noise

Interference to wireless systems can occur from a variety of sources. These sources include atmospheric noise, galactic noise, man-made noise, radio noise and receiver noise.

In a wireless communication systems, the receiver will only provide useable signal if the signal to noise ratio, sometimes referred to as carrier to noise ratio, is above a specified value. This value of acceptable signal to noise ratio is typically different for each receiving system and cannot be quantified here.

During system design, it is necessary to understand how the antenna and receiver contribute to the system noise level. In estimating interference or noise levels at the receiver, the antenna properties of pattern, gain and orientation must be considered. Additionally, the noise levels at various stages in the receiver must be known.

Although noise power level can be expressed in Watts, it is generally accepted to express noise level as a temperature. This concept is based on the Nyquist relation that defines the noise power from a resistor to be a function of Boltzmann's constant (1.37×10^{-23} joule/^{o}K), bandwidth, and absolute temperature. No additional background on this subject will be provided here.

In a receiver system, the noise temperature generated by the antenna may be found in a similar manner. The noise temperature of an antenna is a direct function of the noise temperature of surrounding objects and the portion of the object "seen" as a function of the antenna's radiation pattern.

Mathematically, the antenna noise temperature is derived from the antenna's gain pattern and the noise temperature profile of the surrounding environment thorough the following formula:

$$T_a := \frac{\int_0^{2\pi}\int_0^{\pi} T(\theta,\phi)\cdot G(\theta,\phi)\cdot \sin(\theta)\, d\theta\, d\phi}{\int_0^{2\pi}\int_0^{\pi} G(\theta,\phi)\cdot \sin(\theta)\, d\theta\, d\phi}$$

To quickly estimate the antenna noise temperature, a much simpler approach can be used. Consider a vertical dipole antenna located above ground. Since the dipole pattern is equal above and below the antenna horizon, 50% of the dipole "sees" the sky and 50% of the dipole "sees" the earth. If we assume that the antenna is 95% efficient and the earth has a temperature of 300 °K and the sky has an average temperature 5 °K, the total noise temperature for the antenna can be estimated as follows:

T_a = antenna efficiency * (sky noise contribution + earth noise contribution)

$T_a = 0.95 * (0.5 * 5 + 0.5 * 300) = 144.8$ K

Although this example is quite simple and has made some basic assumptions about the noise temperatures levels in the surrounding environment, it illustrates the concept used to determine noise temperature for an antenna. In an actual system design, the antenna noise temperature would have been calculated by using the formula presented above.

Polarization Distortion

As radiated waves propagate they are subject to a multitude of reflections, refractions and diffractions as described by the multipath phenomena. An another potential phenomenon that these signals may undergo is a change in their polarization. This change will occur differently for linearly and circularly polarized waves.

By simple reflection off a metallic object, a circularly polarized wave will change sense. After reflection, a right hand circular wave will become left hand circular and vice versa. For linearly polarized waves the change is not as straight forward. A vertically or horizontally polarized wave striking a smooth metal object will not change its polarization orientation. A

horizontally wave, however, will undergo a 180 degree phase change (hence the above described change in a circularly polarized wave).

The mechanism that changes the polarization in linear polarized waves is the orientation of objects struck by the wave. As linearly polarized waves strike metallic and dielectric objects they are reflected or diffracted. If the objects that these waves strike have some component of orientation that is not parallel with the polarization of the incident wave, the reflected wave will have a different polarization sense and may no longer be truly linear.

This is an important issue to consider at the receive site of the wireless terminal. It may be that a linearly polarized antenna in the same orientation as the transmit antenna may not provide optimum signal reception.

The Effects of Earth and Other Surrounding Objects

Most, if not all antenna performance characteristics are specified under free space conditions. It is important to realize that these performance characteristics may change once the antenna is located in its operating environment. Surrounding objects, such as the earth, walls, buildings, floors, etc. will impact the antenna's specified performance. The fact that antenna performance may change in the operating environment does not invalidate the use of free space data. It is impossible to specify performance for all environments and the free space performance characteristics provide the most suitable reference for comparing antenna performance.

Rather than discussing how the earth or other surrounding objects attenuate, reflect and diffract RF radiation (multipath), this section will briefly describe the significant ways in which the earth directly affects antenna performance. The earth is used as the principle example for discussion, however, the same concepts can be applied to other surrounding objects such as walls and buildings.

Aside from contributing directly to antenna noise temperature (interference), the presence of the earth affects an antenna's radiation pattern and impedance characteristics. The earth acts as a dielectric body with varying conductivity (σ) and dielectric constant (ε_r). Although values of conductivity and dielectric constant vary with frequency and conditions over the earth's surface, typical values for σ and ε_r are 12×10^{-3} mho/m and 15, respectively.

When an antenna is located near the earth, its radiated field couples with the earth and changes. The antenna impedance is changed from its free space value by the addition of a

component known as ground resistance or ground impedance. The presence of this component changes how RF energy is delivered to the antenna in that some energy normally radiated by the antenna is now dissipated in the earth. This characteristic is described by the following equation that describes the total antenna resistance,

$$R_a = (R_r + R_L + R_g)$$

where R_r is the radiation resistance, R_L is the antenna loss resistance and R_g is the ground resistance. The total energy delivered to the antenna is distributed among these three components. Any energy delivered to R_L and R_g is not radiated but dissipated as heat. This will reduce the system efficiency.

In addition to impacting the antenna impedance, the earth also changes the antenna's radiation pattern. The change in radiation pattern is directly related to the earth's ground constants, σ and ε_r, as well as the antenna's polarization and height above ground.

When an antenna is located over the earth, an "image" is generated in the earth as shown in Figure 5. This image will contribute to the total radiated field by the vector sum of the direct and reflected waves. This is essentially a multipath phenomena and illustrates how the transmit and receive antenna height affects pattern performance.

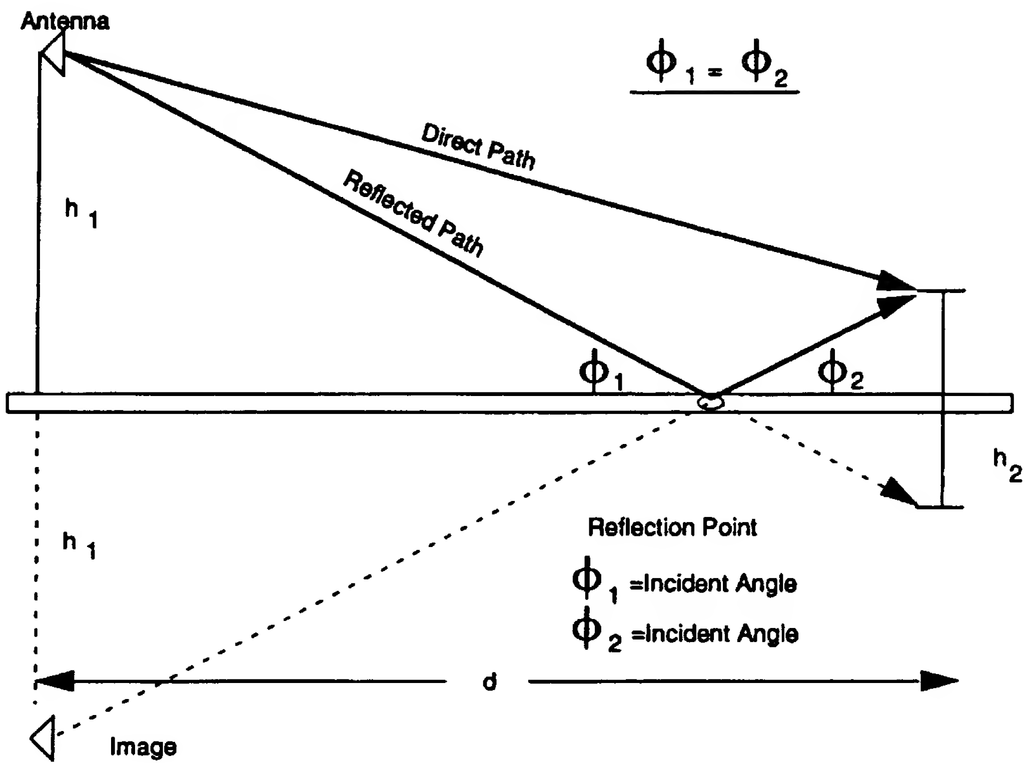


Figure 5. Illustration of Antenna Image in Earth

To provide an illustration of this concept, consider a vertical dipole antenna located 25 feet above the earth and operating at 915 MHz. Figure 6 presents a comparison of the dipole free space pattern and the pattern over ground. The radiation pattern of the dipole over ground has a number of amplitude nulls (multipath effect) which would reduce coverage to a receiving antenna depending upon its height and distance from the dipole.

In designing a wireless system it becomes necessary to understand how the earth and other surrounding objects impact antenna performance. Selection of both the transmit and receive antenna height will play a significant role optimizing system performance.

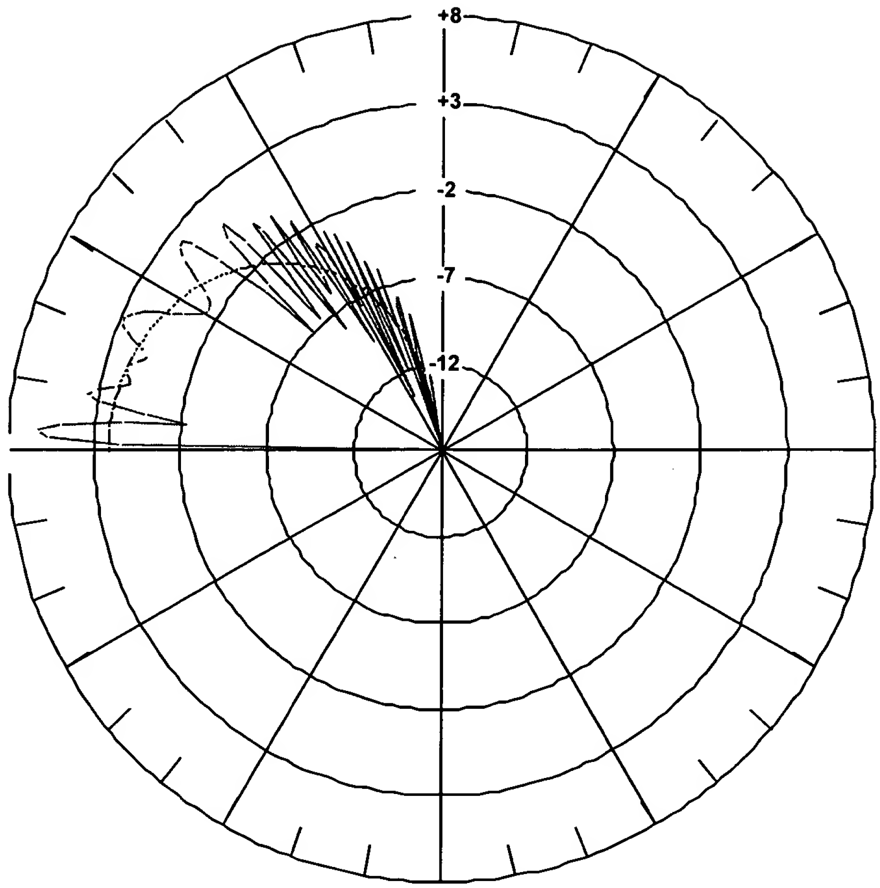


Figure 6. Pattern Comparison of a Dipole Antenna in Free Space and over Earth.

ANTENNA SELECTION FOR OPTIMIZING PERFORMANCE

Having provided the above discussion on antenna and RF propagation properties, and their potential impact on wireless system performance, the next question is how do these issues relate to selection of an appropriate antenna system.

When implementing a wireless communication system in a specific environment, both the system operator and end user must consider several basic issues. These issues include, but may not be limited to, service level, performance, reliability and cost. Three of these issues, performance, reliability and cost are also factors to consider during the selection of system antennas.

Reliability and cost are typically straight forward to evaluate. System performance, however, is a function of many unknowns. From a customer viewpoint, the only concern is maintaining the communication link. Along this line of thought, the basic issue for the antenna system can be summarized in one word: coverage. As previously discussed, all of the antenna and RF propagation properties affect system coverage. One other factor that will impact coverage and performance is antenna location. Optimizing the location of an antenna generally becomes a significant issue in optimizing system performance.

Considering the antenna properties separately, the following general statement can be made. First, VSWR is generally not an issue as a 1.5:1 or 2.0:1 VSWR should be realizable with any of the wireless system antennas.

The antenna radiation pattern and beamwidth requirements are really a function of where the various access points or stations are located. In every installation, the antennas should be made as directive as possible so as to only provide pattern coverage where needed. This should help to enhance signal strength thus minimizing interference and multipath effects. Unfortunately, many if not all installations require some omnidirectional coverage. Selection of appropriate antenna location is important in defining pattern performance requirements.

The antenna gain requirement is not necessarily a simple performance characteristic to specify. The antenna gain must be sufficient to ensure signal reception, but it may also be limited by FCC regulations. Gain should be optimized within pattern and regulatory constraints.

The antenna polarization is another characteristic that is not simple to optimize. As signals propagate there is a potential for their polarization to change. This is especially true more so with indoor propagation than with outdoor. In an indoor system, it is possible that optimum signal transfer between a transmit and receive antenna may not occur if both are identically polarized (assuming the propagation path is not direct). Many attempts at improving coverage as a function polarization have been tried and are used quite frequently. These include the use of dual polarized (vertical linear and horizontal linear), dual slant linear 45 degree polarization, and circular polarization. The use of dual linear polarization is an advantage if the true polarization has become closer to the orthogonal linear sense. It allows reception of both polarizations simultaneously. Dual slant linear 45 degree polarization is the same as dual vertical and horizontal except that the polarization has been rotated 45 degrees in an attempt to minimize polarization mismatch loss. A third polarization option is circular which will receive any of the linear polarizations. The disadvantage is the polarization mismatch loss as detailed earlier.

Once an antenna with a given pattern, gain and polarization has been selected, the other issues regarding RF propagation become significant. Path loss will obviously limit system range and can only be overcome by reducing system losses, increasing antenna gain or output transmit power. These may not always be practical solutions.

Optimizing antenna location can reduce multipath and interference problems. This includes antenna height as well as location relative to nearby objects. Protecting against multipath fade zones is difficult and it may be that other techniques such as diversity are required to reduce multipath interference. Other interference sources are difficult to control and require ensuring a sufficient signal to noise ratio via antenna location, gain and reduction of system loss.

Overall antenna selection and location optimization is not an arbitrary task. It does require an evaluation of system coverage and range requirements, a review of station locations, and a review of surrounding objects that may become a source of interference.